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# Evaluation of proxies for European and North Atlantic temperature field reconstructions

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[1] We evaluate the importance of high-resolution proxies for boreal winter (October to March) and summer (April to September) European and North Atlantic temperature reconstructions. Multiple regression, backward elimination and cross-validation techniques are used to achieve this goal. The analysis considers natural proxies and synthetic "pseudo-documentary indices". The results suggest that the most valuable predictors for European winter temperature are documentary-based indices, while tree-rings performed best for the warm season. It was also shown that the temperature signal in a speleothem from Scotland may be used for further winter and summer temperature reconstructions over parts of the Atlantic Ocean. This study represents a step towards the optimal selection of proxies which will improve temperature reconstructions. *INDEX TERMS:* 1620 Global Change: Climate dynamics (3309); 3344 Meteorology and Atmospheric Dynamics: Paleoclimatology; 4215 Oceanography: General: Climate and interannual variability (3309). **Citation:** Pauling, A., J. Luterbacher, and H. Wanner, Evaluation of proxies for European and North Atlantic temperature field reconstructions, *Geophys. Res. Lett.*, *30*(15), 1787, doi:10.1029/2003GL017589, 2003.

## 1. Introduction

[2] In the context of understanding natural climate variability, improving spatio-temporal high-resolution climate reconstructions is a key issue. Reconstruction skill is related to the inherent climate signal within potential predictor datasets. A number studies [*Briffa et al.* 1988, 2001, 2002; *Schweingruber et al.* 1991] have shown that tree-rings can skillfully reconstruct warm season temperatures for Europe and the adjacent North Atlantic region. 'Multi-proxy' networks (comprising natural archives such as ice cores, tree-rings, laminated sediments and corals in combination with long instrumental time series and historical documents) have also been used to estimate spatial European patterns of annual temperature [*Guiot* 1992; *Mann et al.* 1998]. Recently, proxy-based annually resolved temperature pattern reconstructions were expanded by *Mann et al.* [2000] in order to develop gridded boreal cold (October–March) and warm (April–September) temperature estimates for Europe back to the mid-18th century. The multiproxy approach exploits the complementary strengths from each of the proxies to estimate temperature changes over a large area back in time [*Mann* 2002].

[3] However, we are not aware of any study which evaluates high-resolution natural and documentary proxies for seasonal temperature estimates over the North Atlantic-European region. Particularly, this contribution aims to statistically determine the most important proxy at each gridpoint over the North Atlantic-European area and how much of the regional temperature variability they account for.

## 2. Data and Methods

[4] Figure 1 depicts the locations of the proxies used in this study (tree-rings, ice cores, corals, one speleothem, one varve and documentary precipitation and temperature series). Most of the natural proxies have been downloaded from the World Data Center (WDC) for Paleoclimatology, Boulder, Colorado, USA. To select temperature-sensitive trees, European pine and spruce chronologies (ring width and density) north of 55°N or higher than 1500 m.a.s.l. have been screened for high correlation with spatially averaged temperature in the study area (see Figure 1). As only few predictors can enter the multiple regression model, the ten best performers were selected. Additional information on the proxies used is provided in the supplementary electronic material[1]. As documentary indices were not available for the 20th century, monthly resolved indices based on instrumental measurements were degraded using a similar approach as *Mann and Rutherford* [2002]: Normally-distributed white noise was added to the series to ensure the resulting pseudo-documentary indices have similar quality as documentary indices derived from historical evidence. We have chosen white noise since the bias of two observations one year apart are believed to be uncorrelated. If we assumed the bias to be red, documentary indices would possibly be favored since temperature series are also slightly red in nature. The signal-to-noise ratios of these degraded indices are based

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[1] Supporting material is available via Web browser or via Anonymous FTP from ftp://ftp.agu.org, directory "apend" (Username = "anonymous", Password = "guest"); subdirectories in the ftp site are arranged by paper number. Information on searching and submitting electronic supplements is found a http://www.agu.org/pubs/esupp_about.html.

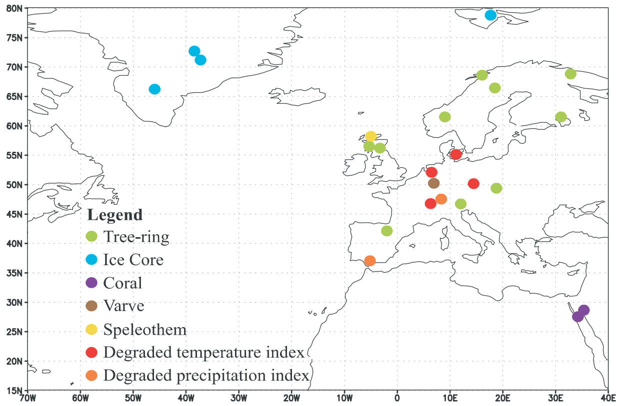

**Figure 1.** Locations of the proxies used in this study. The spatial coverage of this map corresponds to the temperature grid used as predictand.

on *Rácz'* [1999] results who found average correlations of 0.56 between monthly temperature indices based on climate history for Hungary and instrumental observations in Budapest between 1780 and 1850. Similar correlations, with varying overlapping periods between documentary and instrumental data, have been found for the Czech Republic [*Brázdil and Friedmannová* 1994; *Brázdil et al.* 2003] and Spain [*Rodrigo et al.* 1999].

[5] The gridded temperature dataset (70°W–40°E; 15°N–80°N, 5° × 5° resolution) from *Jones and Moberg* [2003] was chosen as the dependent variable. The common period (1871–1974) of both the predictors and the predictands was used for calibration. Since different proxies may record climate conditions at different times of the year, we study the performance of the proxy information for both the boreal cold (October–March) and warm (April–September) season.

[6] First, for each gridpoint multiple regression models were established. Second, all but one predictor at each gridpoint were eliminated using backward elimination techniques [e.g. *Ryan* 1997]. The last predictor at each gridpoint is regarded as the most important one of the initial predictor set. To reduce the time-dependence of the calibration equations we used all observations for calibration and performed verification using cross-validation techniques [e.g. *Michaelsen* 1987]. To keep autocorrelation between the predicted values and the remaining observations low, we have chosen a "leave-out-three procedure" which runs the model 104 times, each time withholding three different but adjacent observations, and then predicts the middle value of the three that were withheld from the dataset. The result is a time series of predicted values. By correlating this predicted temperature series with the observations the regression model could be verified.

## 3. Results

[7] Figure 2 presents the spatial distribution of the last remaining predictor at each gridpoint for the boreal cold season, derived through backward elimination (left panel) and the corresponding explained variance from cross-validation (right panel). The pseudo-documentary indices are the most important predictors over large parts of continental Europe, explaining approximately 20% of the variance. The speleothem from Scotland proved to perform better in the models than other predictors above all over southern parts of the North Atlantic. It accounts for up to 30% of the cold season's variance. Tree-rings are most important for winter temperature over parts of the central North Atlantic. However, the explained variance is rather low and generally resolves less than 10% of the regional October–March temperature variability. Ice cores are the most important predictors for the cold season temperature around Greenland and over parts of the subtropical Atlantic sharing around 10% of the variance. For only a few gridpoints are the Red Sea corals the best predictor as they appear to represent only regional temperature conditions.

[8] The left panel of Figure 3 shows the most important predictors for the boreal warm season at each gridpoint while the right panel shows the corresponding explained variance from cross-validation. Compared to the cold season, the tree-rings have taken the place of the pseudo-documentary temperature indices (except over Italy). Tree-rings explain between 20% and 40% of the northern European temperature variability. It is mainly density data that correlates strongly with summer temperature. Further, tree-rings are important predictors for temperature over parts of the central Atlantic. As for the cold season, the speleothem is generally the

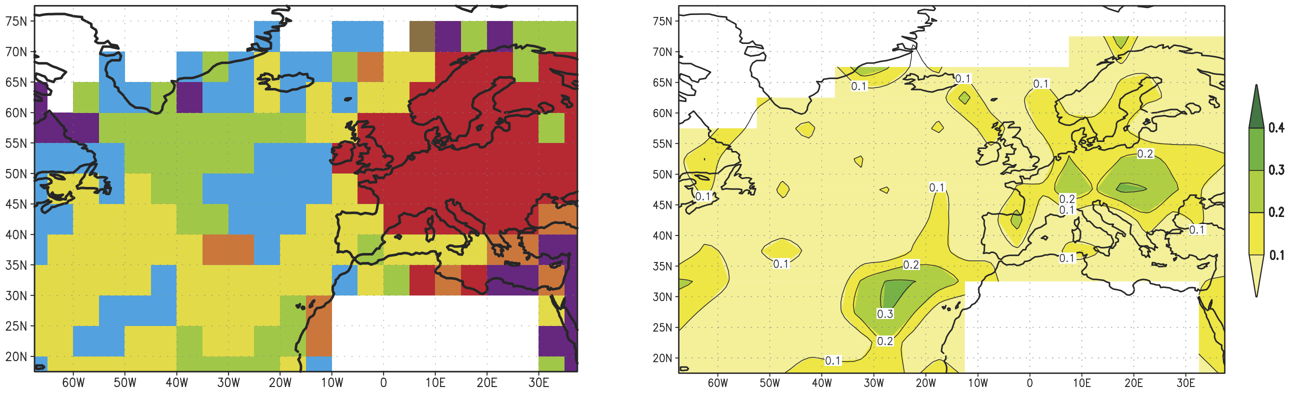

**Figure 2.** Spatial distribution of the most important predictors for boreal winter (October to March) temperature (left panel). For the legend see Figure 1. The right panel shows the corresponding explained variance from verification. White areas indicate missing data.

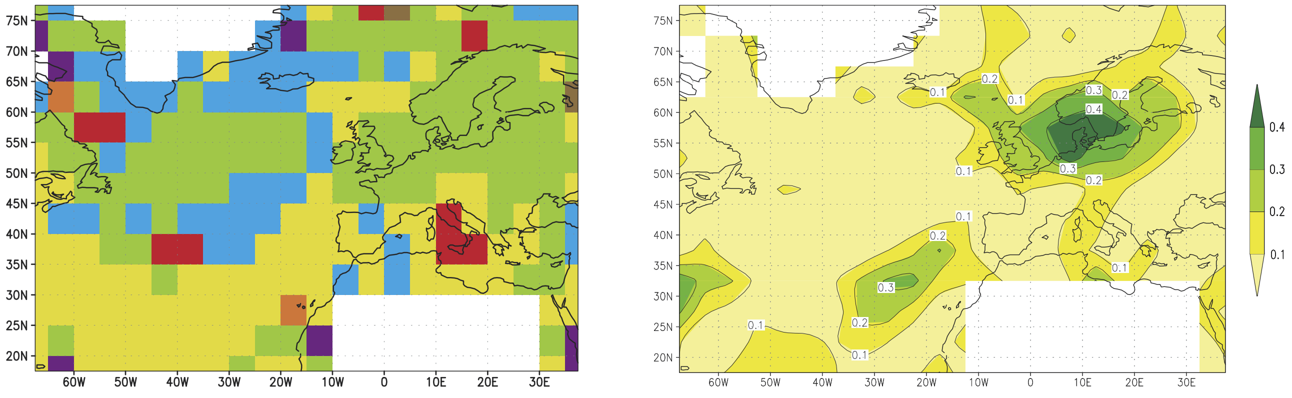

**Figure 3.** As Figure 2 but for boreal summer (April to September) temperature as predictand.

strongest predictor over the Atlantic south of 40°N with shared variance ranging from below 10% to 30%. The regions where ice cores are most valuable during summer cover similar areas as during the cold season. This proxy accounts for up to 20% of the growing season's temperature variance.

[9] For only very few gridpoints were the varve identified as the strongest predictor. This finding applies only to the used varve and surely cannot be generalized. The relative poor performance of the degraded precipitation indices is possibly due to the weak relationship between temperature and precipitation.

## 4. Discussion

[10] The results suggest that the integrated summer temperature signal of tree–rings is more accurate than the one derived from historical weather observers (Figure 3). This is not surprising since tree–rings are known to be sensitive to the growing–season [e.g. *Briffa et al.* 2001, 2002]. However, the pseudo–documentary indices proved to perform better than the other proxies for European winter temperature (Figure 2). A reason for this could be that observers in historical times made direct observations of the weather related to temperature while tree–rings just respire during winter and do not allocate carbon. Correlations between winter temperature and tree–rings are at least partly due to winter–summer temperature correlations.

[11] The areas where the speleothem is the best proxy cover large areas of the North Atlantic Ocean and parts of the bordering land areas in both seasons. Generally, growth of this Scottish speleothem is promoted by warm and dry conditions [*Proctor et al.* 2000]. Moreover, the observed pattern of explained variance (Figures 2 and 3) has similarities to the correlation pattern between the North Atlantic Oscillation (NAO) and Sea Surface Temperatures (SSTs) reported by *Slonosky and Yiou* [2002]. Hence, these results suggest that there is a linkage between speleothem growth, SSTs and the NAO. However, *Proctor et al.* [2002] reported on temporal instabilities in the stalagmite growth rate–SST relationship. We found similar results for air temperature when performing experiments using different calibration/verification intervals in the period 1871–1974 (not shown) revealing that the results presented here are only valid for the 104-year calibration period. If temporal extrapolation is possible needs to be verified. Further, *Proctor et al.* [2002] found the highest SST-stalagmite correlation north of Iceland. However, the cross-validated results do not confirm this finding using air temperature despite the SST-air temperature linkage.

[12] The value of the ice cores in reconstructing temperature around Greenland is probably related to the local temperature signal in the $\delta^{18}$O series [*Johnsen et al.* 1989]. Ice cores are also important predictors for winter temperature over the subtropical North Atlantic. This could be attributed to the importance of this part of the Atlantic as moisture source for the Greenland ice sheet [*Johnsen et al.* 1989].

[13] Coral $\delta^{18}$O series also reflect SST [e.g. *Felis et al.* 2000]. The importance of the corals for local winter air temperature (Figure 2, left panel) may be due to the linkage between SST, air temperature and large-scale atmospheric circulation. Interestingly, there is only a winter temperature signal in the $\delta^{18}$O series of the Red Sea corals. We attribute this to enhanced advection of relatively cold air from southeastern Europe over the eastern Mediterranean towards the northern Red Sea region [*Rimbu et al.* 2001].

[14] It should also be taken into account that not only the proxy type determines the results of this study (Figures 2 and 3) but also its initial number and location. However, especially the speleothem shows that the importance of proxies does not depend on how many proxies of each type entered the backward elimination process. Also, despite the importance of the proxy location, the proximity of tree-rings and the speleothem in Scotland as well as the vicinity of pseudo-documentary indices and tree-rings in central Europe suggest that the proxy characters are competing in the backward elimination process and not the proxy locations.

[15] The analysis was also performed for annual temperature (see the electronic supplementary material[1]). Especially over Central Europe the distribution of the most important predictors is closer to the winter than to the summer pattern. A reason may be that temperature trends are generally stronger in winter than in summer. *Mann et al.* [2000] reported that the seasonal information in the multiproxy networks allows more effective reconstructions at the annual scale than particular seasonal conditions. In our study we found that there is no substantial difference between the performance of the proxies for a particular season or for annual averages, except for northern Europe (warm season) where a higher fraction of the seasonal variance is calibrated.

[16] We also performed a similar analysis, using the full multiproxy model (i.e. without any backward elimination using all the 27 predictors; see the electronic supplementary

material[1]). The pattern remained more or less the same which indicates that much of the temperature variance can be captured by only few but good predictors. This is supported by *Bradley* [1996] who concluded from an ‘optimum site analysis’ using a 1000 year GCM simulation that much of the global temperature can be accounted for by selecting data from only a few sites.

## 5. Conclusions and Outlook

[17] In this study we evaluated the importance of natural and documentary-based proxies for boreal winter and summer temperature reconstructions in the European-North Atlantic region. We found that in both seasons over large parts of the North Atlantic the spatial distribution of the most important proxies and the corresponding fraction of explained temperature variance is similar. Degraded temperature indices with a similar signal/noise ratio as “real” documentary indices proved to be the most important predictors over large areas of continental Europe for winter temperatures while tree-rings are the strongest predictors for the boreal warm season over Europe and parts of the Atlantic and the eastern Mediterranean.

[18] The Scottish speleothem record appears to be a valuable predictor variable for large parts of the North Atlantic and adjacent land areas during both seasons but the explained variance significantly varies over space. These conclusions are only valid for the investigated time period since relationships may change as climate forcings change.

[19] Further, it has been shown that different proxy types have their specific response region, which suggests to use region-specific multiproxy sets in seasonal temperature reconstructions. Therefore, the optimal combination of predictors for each gridpoint should be identified. In order to verify the above conclusions more systematic testing of a larger dataset of proxies is needed, considering additional data from Europe, North America and East Asia.

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## References

Bradley, R. S., Are there optimum sites for global paleotemperature reconstruction?, in *Climatic Variations and Forcing Mechanisms of the Last 2000 Years*, Vol. 41, edited by P. D. Jones, R. S. Bradley, and J. Jouzel, pp. 603–624, Springer Verlag, Berlin, 1996.

Brázdil, R., and L. Friedmannová, Temperature patterns in the Czech Lands in 1751–1850 - comparison of documentary evidence and of instrumental data, in *Contemporary Climatology* edited by R. Brázdil and M. Kolář, *Proceedings of the meeting of the Commission on Climatology of the International Geographical Union, 15–20 August 1994*, Brno, Czech Republic, 82–92, 1994.

Brázdil, R., H. Valášek, and J. Macková, Climate in the Czech Lands during the 1780s in the light of daily weather records of Parson Karel Bernard Hein of Hodonice (south-western Moravia): Comparison of documentary and instrumental data, *Clim. Change*, in press, 2003.

Briffa, K. R., P. D. Jones, and F. H. Schweingruber, Summer Temperature Patterns over Europe: A Reconstruction from 1750 A.D. Based on Maximum Latewood Density Indices of Conifers, *Quaternary Research*, *30*, 36–52, 1988.

Briffa, K. R., T. J. Osborn, F. H. Schweingruber, I. C. Harris, P. D. Jones, S. G. Shiyatov, and E. A. Vaganov, Low-frequency temperature variations from a northern tree-ring-density network, *J. Geophys. Res.*, *106*, 2929–2941, 2001.

Briffa, K. R., T. J. Osborn, F. H. Schweingruber, P. D. Jones, S. G. Shiyatov, and E. A. Vaganov, Tree-ring width and density data around the Northern Hemisphere: part 1, local and regional climate signals, *The Holocene*, *12*, 737–757, 2002.

Felis, T., J. Pätzold, Y. Loya, M. Fine, A. Nawar, and G. Wefer, A coral oxygen isotope record from the northern Red Sea documenting NAO, ENSO, and North Pacific teleconnections on Middle East climate variability since the year 1750, *Paleoceanography*, *15*, 679–694, 2000.

Guiot, J., The combination of historical documents and biological data in the reconstruction of climate variations in space and time, *Paleoclimatic Res.*, *7*, 93–104, 1992.

Johnsen, S., W. Dansgaard, and J. White, The origin of arctic precipitation under present and glacial conditions, *Tellus*, *41B*, 452–468, 1989.

Jones, P. D., and A. Moberg, Hemispheric and large-scale surface air temperature variations: an extensive revision and an update to 2001, *J. Clim.*, *16*, 206–223, 2003.

Mann, M. E., The Value of Multiple Proxies, *Science*, *297*, 1481–1482, 2002.

Mann, M. E., R. S. Bradley, and M. K. Hughes, Global-scale temperature patterns and climate forcing over the past six centuries, *Nature*, *392*, 779–787, 1998.

Mann, M. E., E. Gille, R. S. Bradley, M. K. Hughes, J. Overpeck, F. T. Keimig, and W. Gross, Global temperature patterns in past centuries: An interactive presentation, *Earth Interactions*, *4*, 1–29, 2000.

Mann, M. E., and S. Rutherford, Climate reconstruction using ‘Pseudoproxies’, *Geophys. Res. Lett*, doi:10.1029/2001GL014554, 2002.

Michaelsen, J., Cross-validation in statistical climate forecast models, *J. Clim. and Appl. Met.*, *26*, 1589–1600, 1987.

Proctor, C. J., A. Baker, W. L. Barnes, and M. A. Gilmour, A thousand year speleothem proxy record of North Atlantic climate from Scotland, *Clim. Dyn.*, *16*, 815–820, 2000.

Proctor, C. J., A. Baker, and W. L. Barnes, A three thousand year record of North Atlantic climate, *Clim. Dyn.*, *19*, 449–454, 2002.

Rácz, L., Climate history of Hungary since 16th century: Past, present and future, Centre for Regional Studies of the Hungarian Academy of Sciences, Pécz, 1999.

Rimbu, N., G. Lohmann, T. Felis, and J. Pätzold, Arctic Oscillation signature in a Red Sea coral, *Geophys. Res. Lett.*, *28*, 2959–2962, 2001.

Rodrigo, F. S., M. J. Esteban-Parra, D. Pozo-Vázquez, and Y. Castro-Diez, A 500-year precipitation record in southern Spain, *Int. J. Climatol.*, *19*, 1233–1253, 1999.

Ryan, P. T., Modern regression methods, John Wiley and Sons, New York, 1997.

Schweingruber, F. H., K. R. Briffa, and P. D. Jones, Yearly Maps of Summer Temperatures in Western Europe from A.D.1750 to 1975 and Western North America from 1600 to 1982. Results of a Radiodensitometrical Study on Tree Rings, *Vegetatio*, *92*, 5–71, 1991.

Slonosky, V., and P. Yiou, Does the NAO index represent zonal flow? The influence of the NAO on North Atlantic surface temperature, *Clim. Dyn.*, *19*, 17–30, 2002.

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